UNSEASONAL FLOODING OF THE BARMAH-MILLEWA FOREST

ANTHONY R. LADSON & JOANNE CHONG

Institute for Sustainable Water Resources, Civil Engineering, Monash University Vic 3800, Australia.
tony.ladson@eng.monash.edu.au

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The Barmah-Millewa Forest is recognised in Australia and internationally as an ecologically significant site. However, river regulation has altered the frequency and pattern of forest flooding, and continues to have adverse environmental effects on the Forest. Compared to natural conditions, flooding is now less frequent in winter and spring and more frequent, unseasonally, in summer and autumn. In particular, small unseasonal floods that cover less than 10% of the forest are eight times more frequent now than before regulation. Unseasonal floods occur when rain leads to reductions in demand for water. Irrigators can cancel orders at short notice and water, which has already been released from upstream storages, continues downriver. Flooding occurs when these flows exceed the capacity of the reach of the river which flows through the forest. We explore the multiple factors that contribute to unseasonal flooding. These factors are related to the way the river regulation system - the infrastructure, rules and institutions - has been established and is operated to maintain the reliability of irrigation water supply. Options to reduce the incidence of unseasonal floods include: changes to the operating rules at Hume Reservoir and increasing airspace at Lake Mulwala.

THE BARMAH-MILLEWA FOREST is the name given to the Barmah Forest in Victoria and Millewa group of Forests in New South Wales that lie alongside the River Murray between Echuca, Deniliquin and Tocumwal (Fig. 1). Together these forests cover an area of 700 km^2 and include red gums (*Eucalyptus camaldulensis* Dehnh.) and associated box forests, woodlands and grasslands, in a mosaic of open water, meadows and marshes that are inundated with varying frequency.

The forest is also a wetland of international significance, recognised under the Ramsar convention (Environment Australia 2001). It has been declared one of the six "Significant Ecological Assets", of the River Murray, by the Murray Darling Basin Ministerial Council under the Living Murray Initiative, which initially aims to maximise environmental benefits at these sites (MDBMC 2003). The management of the Barmah-Millewa Forest, along with other river red gum forests located along the River Murray and its tributaries in Victoria, is also the focus of a current investigation by the Victorian Environmental Assessment Council (VGG 2005).

The flow and ecological characteristics of the Barmah-Millewa Forest have been determined by the unique geomorphic features of this region. In particular, the Forest contains the "Barmah Choke" – the reach of the River Murray which has the lowest channel capacity between Lake Hume and South Australia (approximately 1800 km downstream of the forest) (Thoms et al 2000). When river flows exceed the capacity of this choke, the forest floods.

The diverse wetland ecosystems of the Barmah-Millewa forest evolved under natural conditions, when frequent winter and spring flooding was alternated with dry conditions during summer and autumn. Flow regulation has greatly reduced winter and spring flooding (Bren et al. 1987; Bren 1988; Maheshwari et al. 1995). Furthermore, flooding is now much more frequent, unseasonally, in summer and autumn (Chong and Ladson 2003).

Flooding of the forest in summer and autumn happens when local rains reduce the volume of water required for irrigation. If irrigators cancel their orders, the water that would have been diverted instead continues downstream and may cause a flood at the constricted section of the River Murray through the Barmah Forest. These events are referred to as "rain rejection" floods, because local rain leads to irrigators rejecting the water that they ordered. Two operational factors aggravate this problem. First, water to meet irrigation orders from Lake Mulwala, upstream of the Barmah-Millewa Forest, must be released at least four days in advance from the Hume Dam, yet water orders can be rejected at short notice and the unwanted water must be passed downstream. Second, the River Murray is maintained at a high level to enable flow to pass through the "Barmah Choke" (to meet downstream water requirements) so there is no capacity to handle

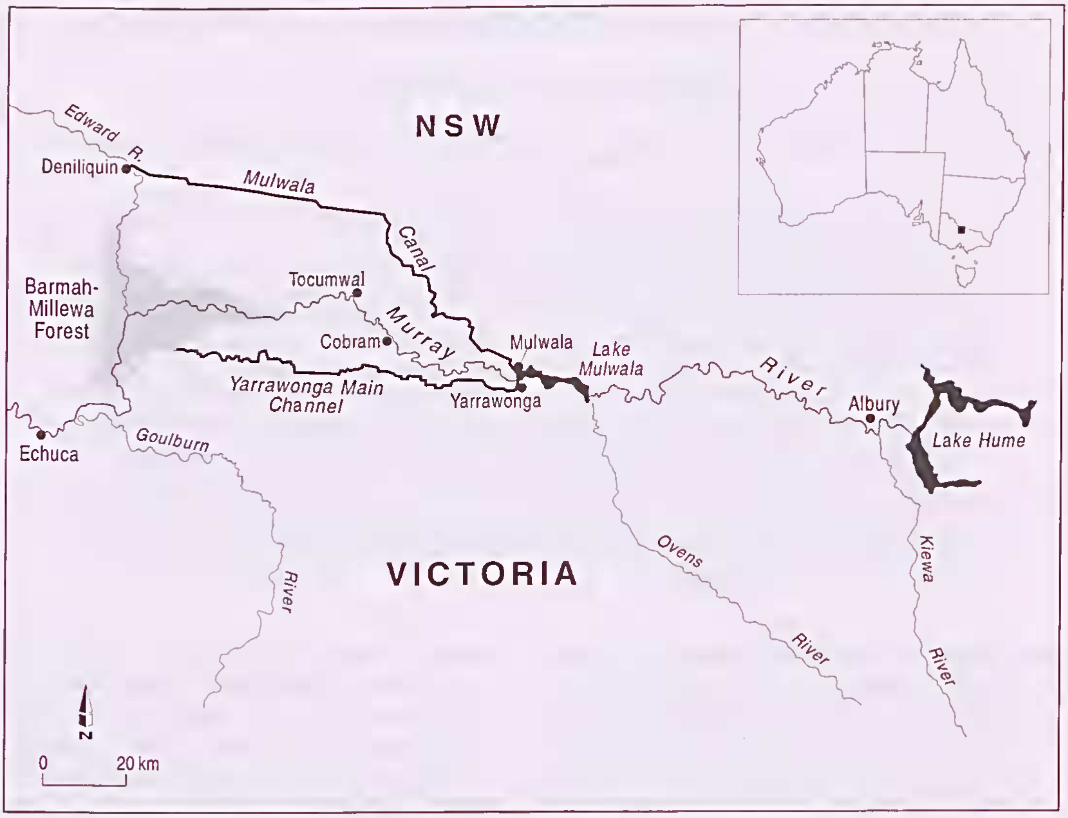

Fig. 1. Location of the Barmah-Millewa Forest (Chong & Ladson 2003).

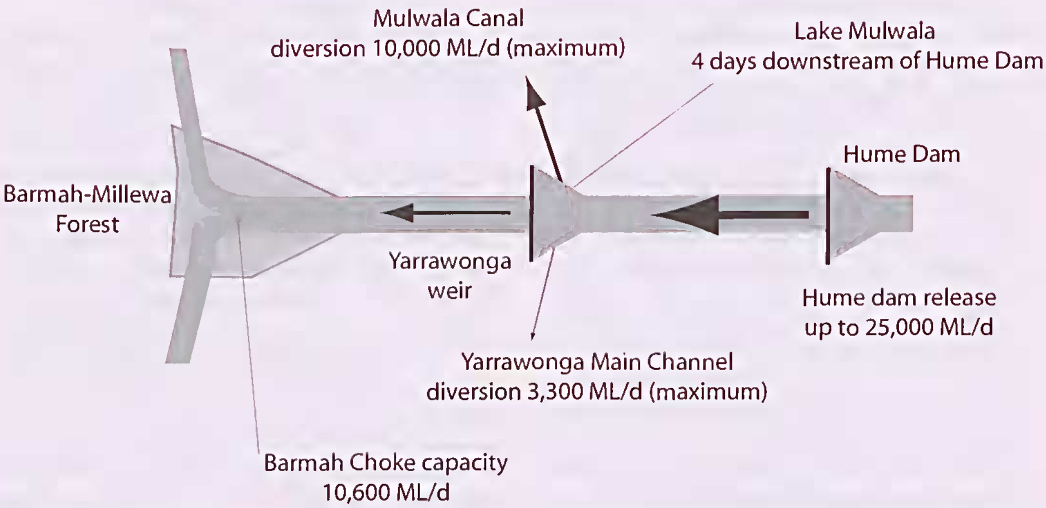

Fig. 2. If irrigators cancel orders, water that has already been released from Hume remains in the river and can flood the Barmah-Millewa Forest.

the extra flows in the river when orders are cancelled. These "rain rejection" flows are often accompanied by increased inputs from the unregulated tributaries (the Ovens and Kiewa Rivers) which are also generated by local rainfall.

These rain rejection floods are common. Based on an analysis of Tocumwal flows we found there was an average of 4.4 events per year, between December and April, from 1983 to 2001. The median duration was 10 days (Chong 2003).

There is significant evidence that riverine ecosystems are affected by the timing, as well as the quantity, of available water. The change in summer/autumn flood frequency and extent of inundation of the forest continues to cause changes in vegetation patterns, with red gum and rushes (*Juncus ingens*) expanding at the expense of Moira grass (*Pseudoraphis spinescens*) plains. Tree death has occurred in some areas because of excess water (Chesterfield 1986; Bren 1992; Leslie and Harris 1996). There are also concerns that flooding results in the loss of regulated flows and causes access problems for fire control, forestry operations, and tourism (RMC 1980).

Management of unseasonal flows (rain rejection management) was listed as being of "very high priority" by a scientific panel set up by the MDBC (Thoms et al. 2000) and is a key project activity under the "Environmental Works Program" of the Living Murray Initiative (MDBMC 2004). However, to date, the major activities conducted to maintain the ecological values of the Barmah-Millewa Forest have focussed on determining and securing annual water allocations to increase winter and spring flooding (Stewart & Harper 2002). There has been limited development of measures to avoid the adverse ecological consequences caused by increased flooding during summer and autumn. At November 2004, the rain rejection project was on hold until sign-off of a preliminary scoping report (MDBMC 2004).

This paper explores the increase in flooding that has taken place as a consequence of regulation. The changes in frequency and extent of unseasonal summer and autumn flooding are summarised followed by discussion of the causes and possible solutions.

A note on units. In this paper, flow rates are expressed using the non-SI unit ML/d (megalitres per day) because this is commonly used by managers of the River Murray. 1 ML/d = 86.4 m^3/s.

THE HISTORY OF RIVER REGULATION AND ITS EFFECT ON UNSEASONAL FLOODING

Although there was occasional summer and autumn flooding prior to regulation, the frequency and extent of unseasonal floods has been greatly influenced by the way the regulated River Murray has been operated to meet increasing demand for water.

Flooding in the Barmah-Millewa Forest was first affected by flow regulation around 1930, when the flow of the River Murray began to be controlled by the operation of the Hume Dam, under construction between 1919 and 1936 and first filled in 1934 (Jacobs 1990).

The low capacity of the reach at the Barmah Choke meant that water, which was intended to satisfy downstream irrigation demand, was frequently lost from the river when it flowed into the forest through flood runners and effluent streams. To retain these flows, earthen banks were constructed to block streams as early as the 1930s (RMC 1980).

The completion of Yarrawonga Weir in 1939 enabled large volumes of water, stored in Hume Dam during winter, to be diverted under gravity to irrigation districts during summer. The ability to control flow in the River Murray, and the volume of water that could be harvested, further increased with the doubling of the capacity of Hume Reservoir in 1961, the diversion of water to the Murray above Hume Dam from 1967 as part of the Snowy Mountains scheme, and the completion of Dartmouth Dam, upstream of Hume Dam on the Mitta Mitta River, in 1979 (Jacobs 1990; Gippel & Blackham 2002). The demand for water and diversion capacity also increased during this time. In particular, the Mulwala Canal was constructed to carry up to 10,000 ML/d from Lake Mulwala to irrigation areas in New South Wales.

The adverse effect of unseasonal flooding on the red gum forest was noted as early as 1954 (Victoria, Parliament 1954). In response, the River Murray Waters agreement was changed to allow the River Murray Commission to undertake coordinated works to decrease loss of regulated flows. These included desnagging (removal of large woody debris from the river channel) to increase capacity and the construction of regulators to control the flow of water from the river (Johnson 1974). Several subsequent studies have canvassed solutions to unseasonal flooding (RMC 1980; Johnson et al. 1980; RMC 1984; DLWC 1996). Although many of the proposed works have been implemented, adverse ecological consequences are continuing.

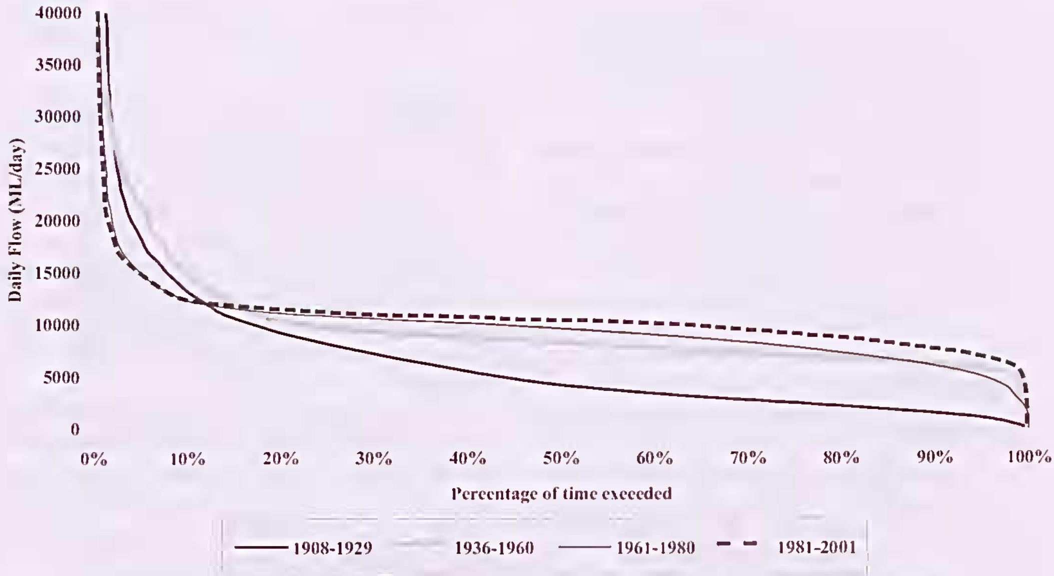

Fig 3. The effect of regulation on flow duration between December and April (River Murray at Tocumwal).

Initially, concerns about unseasonal flooding focussed on loss of water and forestry operations. Over time, there has been increasing recognition of the costs associated with environmental degradation and reduced access for recreational use. More recent work has also returned to the issue of water loss because, for example, additional water savings are being sought for environmental flows (ACIL 2003).

Unseasonal flooding can be quantified by analysing historical flows in the River Murray. The flow record at Tocumwal, near the upstream extent of the Barmah-Millewa Forest, is available from 1908 to the present and can be divided into four periods to illustrate the impact of major changes in flow regulation: pre-regulation 1908 to 1929; post Hume 1936 to 1960; post Hume enlargement 1961 to 1980; and current (post Dartmouth) 1980 to 2001. The effect of regulation on December to April flows at Tocumwal is shown in Fig. 3. The period of December to April was adopted for analysis because it is in these months that flow regulation increases flooding frequency, with adverse ecological consequences (Chong 2003). Fig. 3 shows that regulation has meant summer flows usually show little variation. For example in the period 1980 to 2001 flow is between 9,000 and 12,000 ML/d for 63% of the time. These flows are near to, or just exceeding, the capacity of this reach of the river. Smaller flows <5,000 ML/d and larger flows >15,000 ML/d are now less frequent than under pre-regulation conditions.

Period	Proportion of time forest flooded
1908-1929	15.5%
1936-1960	20.3%
1961-1980	28.5%
1981-2001	38.5%

Table 1. The effect of flow regulation on frequency of flooding of the Barmah-Millewa Forest between December and April (regulation commenced in 1929; current conditions can be approximated by the post 1980 flow record).

Regulation has changed the river's flow regime and this can be related to forest flooding. Overbank flooding into the Barmah-Millewa forest begins to occur at 10,600 ML/d at Tocumwal (downstream of Yarrawonga) (Thoms et al. 2000). This threshold, combined with the Tocumwal flow record, allows historical analysis of flooding occurrence between December and April for each year when Tocumwal flows are available (Table 1). Results show the forest floods more often now than in the past.

It is also possible to calculate the impact of regulation on the areal extent of forest flooding. Bren et al. (1987) established a relationship between the flow at Tocumwal and the fraction of the forest that was inundated. Combining this relationship with the Tocumwal flow record shows that, in summer and

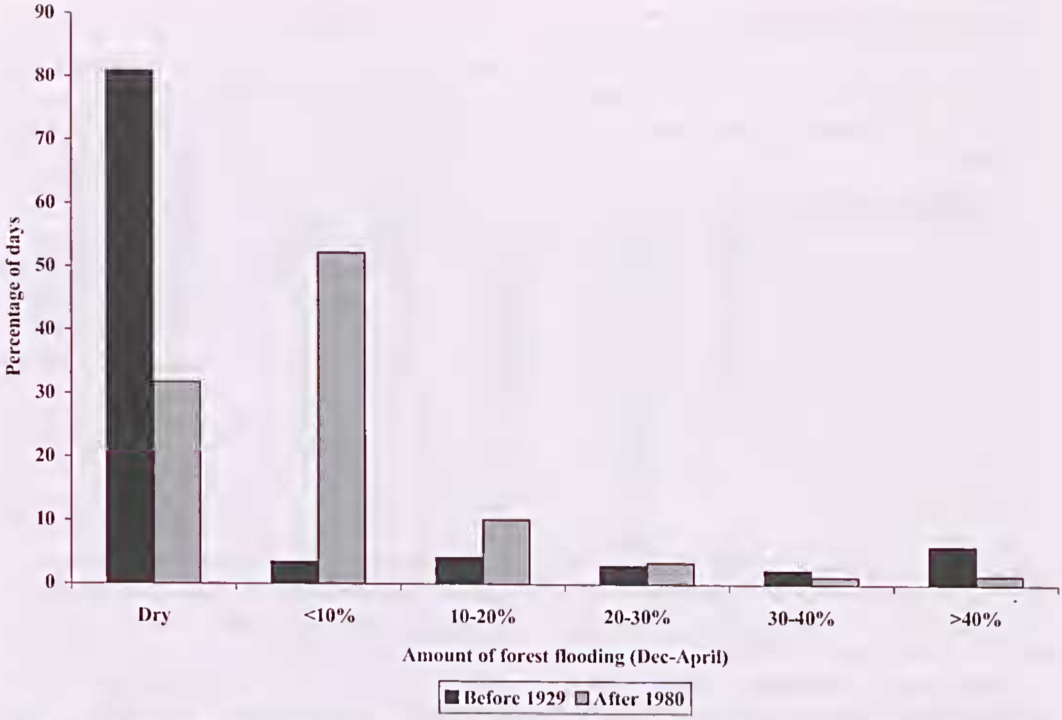

Fig 4. The effect of flow regulation on the extent of flooding of the Barmah-Millewa Forest between December and April (regulation commenced in 1929; current conditions can be approximated by the post 1980 flow record).

autumn, certain areas of the forest are flooded more frequently and are thus subject to ecological damage (Fig. 4). For example:

- The proportion of days during which the entire forest is dry has decreased from 80.9% in 1908-1929 to 31.8% in 1981-2001;
- The proportion of days during which 0-30% of the forest is flooded has increased from 10.7% to 65.9% of the time; in particular, floods which cover less than 10% of the Forest have increased in frequency by 8 times, from 6.5% to 52.3% of days;
- The proportion of days during which over 30% of the forest is flooded has decreased from 8.4% of the time to 2.3% of the time.

The Murray-Darling Basin Commission has established operating guidelines which aim to reduce forest flooding by limiting flows at the Barmah Choke. However, analysis of flow levels reveals that this approach has not been effective. Compliance is based on the water level at Picnic Point (Gauge 409006) at the junction of the Murray and Edward Rivers. From 1996 to 2002 the maximum operating water level was set to 2.53 m and after February 2002 this was revised to 2.60 m. The recorded summer water levels at Picnic Point show these operating targets are often exceeded (Fig. 5), which suggests unseasonal flooding is an on-going problem.

OPTIONS TO DECREASE UNSEASONAL FLOODING

There are many elements of the river system which contribute to increased frequency of unseasonal flooding, including: the operation of Hume dam and Yarrawonga weir, management of the irrigation areas supplied from Lake Mulwala in Victoria and New South Wales, the Barmah Choke, and the demand for water downstream. Each of these is considered below to identify possible solutions to the unseasonal flooding problem.

Hume dam

Water must be released from Hume in advance to meet irrigation orders supplied from Lake Mulwala. If there is widespread summer rain and many orders are eancelled, release from Hume is cut back to minimise the excess flow that eontributes to forest flooding. However, there are two operational charaeteristics which limit the extent to which unseasonal flooding of the Barmah-Millewa Forest can be prevented.

First, there is an operating rule (the "six ineh rule") that specifies how quickly flow can be redueed. This limit, set in the 1950s and purportedly related to the risk of bank slumping, is that the water level ean only be reduced by 150 mm (6 inehes) per day downstream of Hume Dam (Arnott 1994; Gippel & Blackham 2002). This eorresponds to a maximum flow reduction of about 1,500 ML/d per day. A severe rain rejection event eould result in the requirement to reduee flows by up to 13,000 ML/d which means it could take a week or more to cut baek the flow.

Second, the diseharge from Hume is often held at high levels for much of the irrigation season. The river capacity downstream of Hume is about 25,000 ML/d and releases are frequently at this level or higher. Releases have also increased substantially over time which makes control of excess flows more diffieult and exacerbates the problems eaused by the "six ineh rule" (Fig. 6).

When the "six ineh rule" was established in the 1950s, the way in which the Hume was operated did not have sueh a large influenee on the extent and frequeney of forest flooding, as under eurrent conditions, because the excess flows assoeiated with rain rejeetions were mueh smaller. The adoption of the "six inch rule" based on a conservative attitude to bank slumping, probably did little harm. Today, this rule adds to the laek of operational flexibility and contributes to environmental damage caused by unseasonal flooding. There is also no evidence of the need for such a striet eonstraint on draw down rates (Green 1999; Gippel & Blackham 2002).

The idea of ehanging operating proeedures at Hume Dam to reduee unseasonal flooding of the Barmah-Millewa Forest is not new. It was first suggested by the River Murray Commission (now the Murray-Darling Basin Commission) in 1980 (RMC 1980), but, as yet, has not been implemented. We suggest that operating proeedures for the Hume Dam should be developed which take account of their impaet on the Barmah-Millewa Forest, as well as loeal coneerns sueh as bank stability.

Yarrawonga Weir/Lake Mulwala

Yarrawonga Weir raises water levels to allow gravity diversion from Lake Mulwala into irrigation areas in Victoria and New South Wales. The frequeney of forest flooding eould be reduced if the weir was operated to eapture some of the rain rejection flows.

To aehieve a reduction in flooding, airspaee (eapacity to store water) must be available at the start of a rain rejeetion event. The lake would fill as exeess flows from Hume were eaptured and then eould be lowered again once irrigation demand increased. In praetiee however, water levels are held in a narrow range.

Although straightforward in prineiple, there are operational eonstraints that limit the flexibility to ehange the operation of Yarrawonga weir. First, the operating range of Lake Mulwala must enable suffieient water to meet irrigators' demands to be delivered by gravity through diversion ehannels. Minimum water surfaee elevations of about 124.8 m AHD are required to deliver the nominal eapacity of the Yarrawonga Main Channel, which diverts water into Victoria, and the Mulwala Canal which takes water into New South Wales (Chong and Ladson 2003).

Second, there appears to be an expectation of reereational users of Lake Mulwala that it will be held nearly full for the summer. The development of a Lake Mulwala management plan, which mentioned the possibility of ehanges to the operating level of the Lake eaused community eoneern (GMWater 2003). Goulburn-Murray Water and the Murray-Darling Basin Commission (the lake managers) both produeed press releases to assure the publie that normal lake operations would continue within the historieal operating range (MDBC 2004). In March 2004, the Boating Industry Assoeiation elaimed, on its website, to have seeured Goulburn-Murray Water's assuranee that the lake would be kept full to maintain its suitability for boating.

We analysed the effect of maintaining a lower lake level on flooding frequency, and found that a small changes in lake level would lead to a signifieant reduetion in unseasonal floods in the Barmah-Millewa Forest without threatening diversion rates (Chong and Ladson 2003). For example, providing 5 Mm^3 additional airspaee (equivalent to a ehange in lake level of 100 mm) reduced the average number of unseasonal flood events from 4.1 to 2.4 per season. Further gains could be aehieved with straightforward engineering works to allow diversions to be maintained at lower lake levels (McLeod pers. com.).

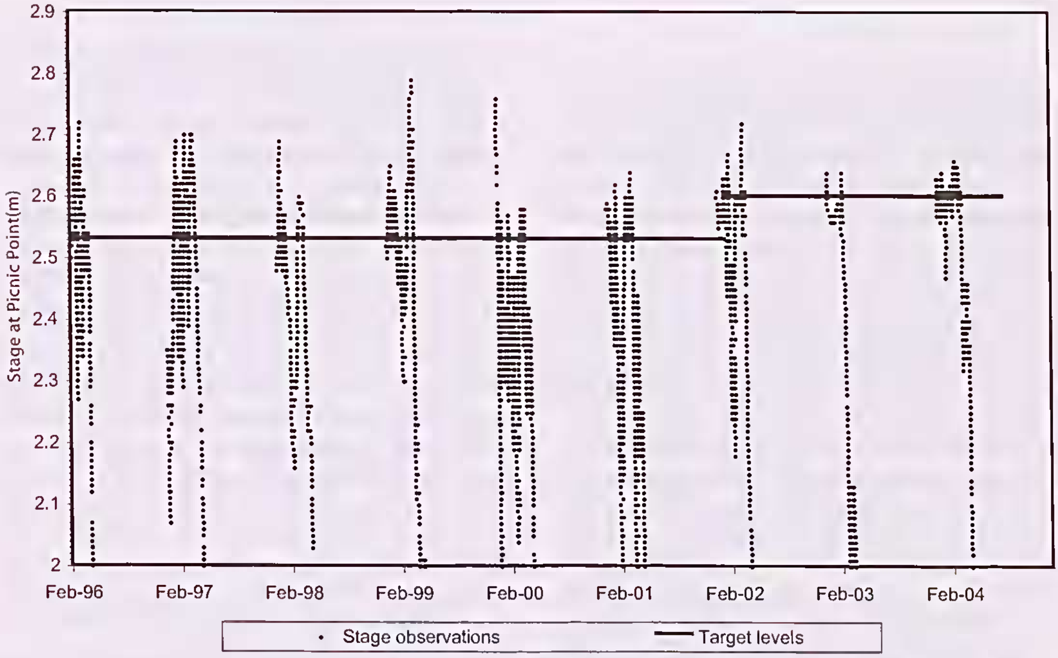

Fig. 5. Water levels of the River Murray at Picnic Point. River operators aim to reduce unseasonal flooding by not exceeding a target water level which was set at 2.53 m between 1996 and Feb 2002 and 2.60 m after Feb 2002. Only water levels Jan to Apr (inclusive) are plotted.

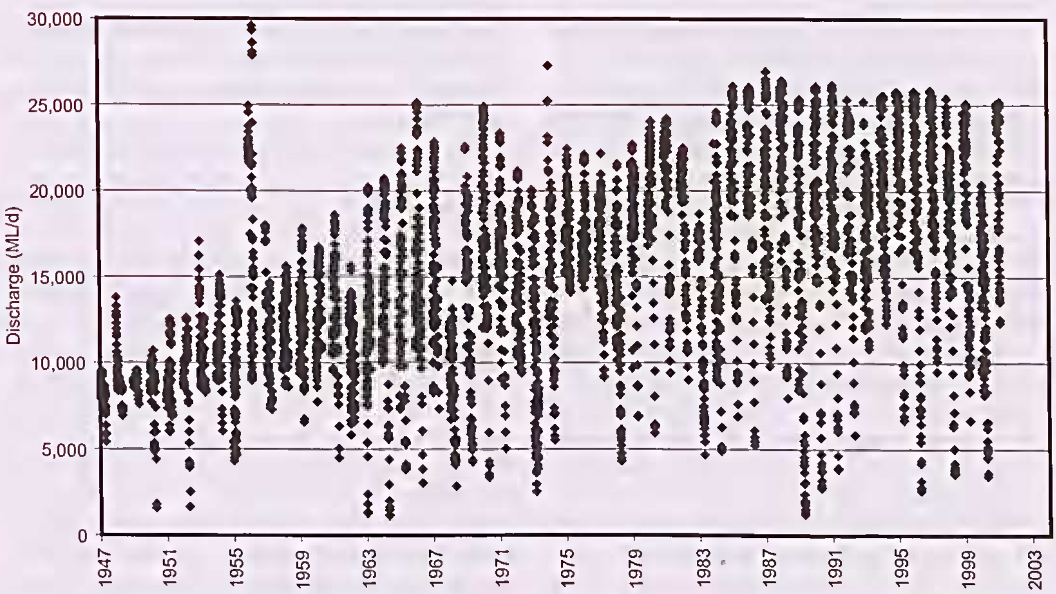

Fig. 6. Releases from Hume Dam during the irrigation season (December to April). Capacity of the River Murray downstream of Hume Dam is approximately 25,000 ML/d.

Irrigation areas

Rules and procedures that govern the operation of the irrigation areas in Victoria and New South Wales also influence forest flooding. Irrigators can reduce water orders at short notice without decreasing their water entitlement or being charged for the water they ordered but did not use. As we have seen, cancelled orders mean that water already released from Hume is not diverted but passes down the river to flood the forest. It is reasonable that water should not be used for irrigation if it is not needed; the challenge is to implement procedures that can cope with rain rejections without causing environmental damage.

One approach would be to use forecasts of summer rain and cut Hume releases early in anticipation of reduced water use. This idea has been around since at least 1974 when Holmes (1974) observed: "reliable forecasting at least four days ahead, may be possible within the next few years, [and] should substantially reduce the frequency of such losses [of water into the forest]". The reliability of forecasting has since improved, but, nevertheless, it is not necessary to use 4-day forecasts to decrease flooding frequency. If either the Hume Dam operators or irrigators considered the next day's rainfall forecasts in their decisions, rain rejection flows might be anticipated and releases from the Hume Dam could be reduced in advance.

The problem is not so much the reliability of forecasts but that neither dam operators nor irrigators bear the risk of ecological damage caused by unseasonal flows, and do not have an incentive to use the information provided in weather forecasts. From an irrigator's perspective, responding to a forecast of rain by cancelling a water order early would leave them exposed to the risk of the forecast being incorrect, and having insufficient irrigation water. The present system, which allows orders to be cancelled at anytime, results in individual irrigators bearing zero risk associated with unexpected rainfall, but maximises the risk of forest flooding.

One approach that may allow improved use of forecasts of summer rain would be for irrigation authorities to calculate expected overall demand based on weather predictions. It should be easier to forecast that it will rain somewhere in an irrigation district than to predict the occurrence of rain on an individual farm. Therefore aggregate water demand could be forecast and the flow from Hume changed accordingly.

There may also be market approaches that could, for example, involve financial rewards to farmers for cancelling their water orders early. An irrigator could then weigh up the risks and benefits of proceeding with, or cancelling, an order based on their expectation of rain and the consequences of missing out on a watering.

Other approaches that have been suggested to decrease rain rejection flows include on-farm storages and on-route storages. On-farm storages could retain water until it was needed which also has the advantage of increasing the flexibility of timing of watering by irrigators. The operation of on-route storages in channels or adjacent to the irrigation systems would allow water from rejected orders to be captured for later use. On-route storages would increase the flexibility of the operation of the water delivery system, save water and allow the capture of rain rejection flows. However, there are also possible disadvantages to these approaches that need to be considered, including loss of arable land to provide storage space, and increased risk of groundwater accessions (DLWC 1996; ACIL 2003).

Barmah Choke

As we have discussed, the physical constraint of the Barmah Choke, combined with a modified flow regime in the River Murray, is the primary cause of unseasonal forest flooding. The lack of capacity of the Barmah Choke has also long been of concern to river operators and irrigators because it constrains water delivery.

The Victorian government's White Paper on water policy states that "Perhaps the most significant congestion point for Victoria is the Barmah Choke" (State of Victoria 2004, p.77). This comment echoes concerns from over 20 years previously, when the River Murray Commission noted that the Barmah Choke was "one of the more important constraints on river regulation of the Murray" (RMC 1984). Irrigators, particularly in horticultural areas where crops are intolerant of water shortages, are concerned that supplies may have to be restricted if insufficient water is passed through the choke. For example, "ensuring security of supply" is listed as the number one goal of Sunraysia Rural Water Authority in its most recent corporate plan (SRWA 2004). There have also been renewed calls for desnagging and channel clearing to increase the delivery of water downstream of the choke (Hunt 2002; *Sunraysia Daily* 16 Sep. 2002, p. 2; Victoria, Parliament 2003).

Water trading, through changing the location and timing of water demand, could also exacerbate the pressure to run the Barmah Choke at full capacity during the irrigation season. There are restrictions that prevent trade from above to below the choke, and there is also a cap on diversions from the River Murray, but trade is having an influence by altering the pattern and magnitude of demand (State of Victoria 2004). Water is trading from the Torrumbarry and Pyramid Hill areas, to horticulture enterprises in the Sunraysia (State of Victoria 2004). This produces more concentrated, peak demands in the summer that must be supplied with water that passes through the choke. As water trading continues, calls to ease the restriction caused by the Barmah Choke are likely to intensify, especially in hot dry summers.

Concerns about restrictions to irrigation have prompted the Victorian State Government, and others, to consider constructing a by-pass channel around the Barmah Choke (State of Victoria 2004; Davis 2003). Although it has been claimed that this will reduce unseasonal flooding by allowing the passage of rain rejection flows around, rather than through, the Barmah-Millewa Forest, it will be important to compare the benefits and costs of a bypass channel, taking into account the way in which it will be operated, against other options to manage unseasonal floods. For example, if the bypass channel was justified as a way to ease water restrictions downstream, it would be operated at full capacity during summer — which means, it would fail to increase the flexibility of the system to deal with rain rejection flows.

In earlier work (Chong and Ladson 2003) we looked at the option for decreasing unseasonal flooding by limiting flows through the Barmah Choke so that there was capacity available to carry rain rejection events. This would, however, decrease the total quantity of water that could be delivered downstream so would increase current concerns about restrictions.

There is perhaps a market solution to these problems. The State Government (State of Victoria 2004) has proposed to define and allow trading in a market instrument related to shares in the capacity of water delivery conduits. To reduce unseasonal flooding, the licensed capacity though the choke would need to be set low enough to provide flexibility to carry rain rejection flows.

CONCLUSION

Summer flooding of the Barmah-Millewa Forest occurs when the flow in the River Murray exceeds the capacity of the reach known as the Barmah Choke and water is spilled into the forest. To address this issue, we need to understand why these excess flows occur. Part of the answer lies with summer rain and cancelled orders for water, but many elements of the river regulation system - the dams, diversion weirs, institutions and rules - contribute to the problem.

In its natural form the River Murray is a complex natural system that technological humans have changed to achieve a relatively simple goal; the provision of water for irrigation. The ecological consequences of this change are great at the Barmah Forest because river capacity here is such a severe operational constraint. We suggest that the underlying cause of unseasonal flooding can be described as the lack of flexibility in the way the River Murray is operated: releases from Hume are commonly near channel capacity; Lake Mulwala is kept near its storage capacity to enable large diversions; the Barmah Choke flows full for much of the year; and water trading, which is shifting supply to the most profitable crops, is intensifying demand (Tisdell 2001). Optimising the river regulation system for water harvesting means there is limited capacity to deal with rain rejection flows. When these flows occur, control is lost and water spills into the forest with adverse environmental consequences.

To reduce unseasonal flooding there needs to be an increase in operational flexibility. We have explored some of the ways this can be achieved including: changes to operating rules at Hume Dam, increasing airspace at Lake Mulwala, water ordering procedures that provide incentive to use weather forecasts, and trading in the share of capacity at the Barmah Choke.

Other system-wide actions that increase flexibility have the potential to decrease unseasonal flooding. For example, the cap on diversions and water recovery projects being undertaken as part of the Living Murray initiative could decrease aggregate irrigation demand and so make management of rain rejection flows easier (Close & McLeod 2000).

Proposed solutions that do not increase flexibility, such as a bypass channel that flows full all summer, should be treated with caution.

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